

**Comment on “Geochemistry of buried river sediments from Ghaggar Plains, NW India: Multi - proxy records of variations in provenance, paleoclimate, and paleovegetation patterns in the late quaternary” by Ajit Singh, Debajyoti Paul, Rajiv Sinha, Kristina J. Thomsen, Sanjeev Gupta**

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Singh et al. (2016) published a geochemical record of sediment compositions from the flood plain of the Ghaggar River in western India and use the changing provenance, particularly as traced by Nd isotope composition, to reconstruct how erosion patterns have changed over the past 100 k.y. In doing so they propose a link between climate change and erosion, and they argue for more erosion from the Higher Himalaya during warmer interglacial periods and more from the Lesser Himalaya during glacial intervals. While we support the concept of erosion patterns being climatically modulated we here take the opportunity to compare the data presented by Singh et al. (2016) to relevant

published records within the region greater Ghaggar region and to open a balanced discussion on how climate and erosion are coupled in the western Himalaya.

Singh et al. (2016) show that after the Last Glacial Maximum, and especially after 14 ka, sediments in their region of the Ghaggar plain exhibit less negative  $\epsilon_{Nd}$  values than before that time (Fig. 1). The authors interpret this trend to younger mean crustal age of the sources as a switch in the erosion away from the Lesser Himalaya towards the Higher Himalaya during the deglaciation. They relate this switch to the extent of glaciation, which they imply protected the High Himalayas from strong erosion during the glacial times. This observation is unexpected because the development in Nd isotope character in the Ghaggar flood plains is the reverse of the trend seen at the Indus delta over the same time interval (Clift et al., 2008)(Fig. 1). These opposing trends either imply that the Ghaggar catchment has the opposite response to climate change to the neighboring Indus basin, which does extend into the High Himalaya, or that other processes are influencing the isotopic character at the two boreholes analyzed by Singh et al. (2016). The suggestion that the sands analyzed by Singh et al. (2016) may have been deposited by a more southward flowing Sutlej River (Sinha et al., 2013)(Fig. 2) would only make the contrast with the delta record more profound because the Sutlej does drain both Greater and Lesser Himalaya and might be expected to parallel the regional trend. Although the Indus, unlike the Sutlej, receives sediment from the Karakoram, which could also influence the bulk isotope U-Pb zircon dating from the delta confirms that the change in basin-wide sediment composition after 15 ka is caused by a relative increase in sediment input from Lesser Himalaya sources (Clift et al., 2008).

It is noteworthy that the reconstructed Ghaggar isotope trend of Singh et al. (2016) is similar both in direction and timing, as well as depth, as that seen at Marot (Fig. 2), downstream of their drill sites (East et al., 2015), as well as at the much more distant section at Kanpur analyzed by Rahaman et al. (2009), and which was already highlighted in their study. Indeed, if we plot the isotope character of the floodplains of the Hakkra River (downstream equivalent of the Ghaggar in modern Pakistan) near Marot we see that they form a single progressive trend, culminating in  $\epsilon_{Nd}$  values of -13 to -14 (Fig. 1). However, explaining this trend as reflecting of a change in erosion patterns within the Himalayan ranges is difficult. The Ghaggar, on whose floodplains the drill sites of Singh et al. (2016) sit, together with the Hakkra drill sites at Marot, Alkasur and Tilwalla (Alizai et al., 2011; East et al., 2015) (Fig. 2), is only draining the Sub-Himalayas, not the Lesser or the Higher Himalaya, so it's not clear how changes in the relative flux from these ranges would have actually impacted the drilled location. If we accept that the sediments are really deposited by the Sutlej, as suggested by Sinha et al. (2013), then it is possible that the relatively negative  $\epsilon_{Nd}$  values prior to 17 ka could be Himalayan (Sutlej) derived, but such flow is known to be finished by 5.2–5.7 ka at the latest (Clift et al., 2012). The fact that the  $\epsilon_{Nd}$  values of the sands considered by Singh et al. (2016) have been consistently more positive than known modern Sutlej compositions since ~17 ka (-17 to -19) (Alizai et al., 2011; Tripathi et al., 2004) also indicates that the drift to more positive  $\epsilon_{Nd}$  values was not caused by changes in the Sutlej basin, which is now more negative, but to mixing with another sediment source. The trend in Ghaggar-Hakkra  $\epsilon_{Nd}$  values is not directed towards a known modern river that could actually have received material from the Lesser and Higher Himalaya. Instead the trend since 14 ka has been

away from the Himalayan draining tributaries but towards the average of the Thar Desert (Fig. 1), similar to the modern Ghaggar, which is perhaps no surprise given its location on the Ghaggar flood plain.

The nearest Himalayan rivers to the Singh et al. (2016) drill sites are the Sutlej and Yamuna that have modern  $\epsilon_{Nd}$  values of -17.0 and -17.7 respectively on the flood plains (Tripathi et al. 2004), with -19 being measured by Alizai et al. (2011) in the Sutlej just before it leaves its headwaters. This compares with an average value of -13.7 for the Thar Desert and -15.6 for the modern Ghaggar. Because the Ghaggar sample of Tripathi et al. (2014) was taken quite far downstream it is likely that at least some of this value represents recycling of Thar Desert sand rather than the composition of the river as it leaves the headwaters. Although the Yamuna or Sutlej would have been affected by changes in the relative strength of erosion between the Higher and Lesser Himalayas, the composition of the sediment studied here is not consistent with either of these rivers being the source because the  $\epsilon_{Nd}$  values are too positive.

The record of Singh et al. (2016) shows a rise in  $\epsilon_{Nd}$  values from around -17 at 17 ka to around -15 at 5 ka. Such a change in isotopic character could be explained by drainage capture. In this scenario, the pre-17 ka section shows the influence of a west flowing river (Saini et al., 2009), possible the Sutlej or even the Yamuna River, whose capture to the modern eastward flow is loosely dated at some time between 49 and 10 ka (Clift et al., 2012). Thus the trends reconstructed by Singh et al. (2016) may reflect the loss of the Sutlej or Yamuna after 17 ka, together with recycling from the Thar Desert that sharply increases after 10 ka, the latter being driven by the weakening strength of the South Asian monsoon. The trend to more positive  $\epsilon_{Nd}$  values in the Ghaggar through the

Holocene does not reflect change in erosion patterns in the mountains themselves, which the delta records show to be the opposite of what is proposed in this study. Alizai et al. (2011) interpreted single grain Pb isotope data from the Hakkra that parallels the Nd isotopes published by East et al. (2015) to reflect evolution of a Himalayan fed stream being clogged by Thar Desert sand as the stream dried up (Giosan et al., 2012). Such a change does not imply a major change of erosion in the source, as proposed by Singh et al. (2016).

If this alternative explanation is accepted then it resolves the apparent discrepancy between the delta and the Ghaggar floodplain isotopic records. Otherwise, it would be difficult to understand why only the Ghaggar would show more Higher Himalayan erosion during post-glacial times when the Indus Basin on a larger scale shows the reverse. Our alternative explanation would also reconcile the trends in regional erosion with the idea that erosion during dry glacial times was focused in the glaciated Himalaya, while the wetter climate after deglaciation shifted the focus into Lesser Himalaya (Clift et al., 2008). In any case, glaciation is generally thought to increase rather than decrease erosion (Hallet et al., 1996) so a trend implying a larger Higher Himalayan flux during deglaciation proposed in the Ghaggar flood plains is enigmatic, although in the short term a local switch to more Higher Himalayan compositions could be driven by recycling from glacial lakes.

Recognition that proximal foreland records do not necessarily reflect erosion in the adjacent mountain chain is an important step in being able to use these sequences to reconstruct long-term environmental and erosional evolution of the mountains and also

emphasize the importance of distal records for understanding orogenic scale responses to climate change.

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## **Figure captions**

Figure 1. Evolution in Nd isotopic character of the whole Indus basin as recorded at the delta, compared to the compositional evolution in the floodplains of the Ghaggar-Hakkra. The results from Singh et al. (2016) are consistent with the earlier dated from the floodplains in modern Pakistan forming a continuous floodplain but from a ephemeral river that did not drain the Lesser or Higher Himalaya. The trend towards desert dune compositions reflects the progressive demise of this river and its choking by the expansion of the Thar Desert during the Holocene.

Figure 2. Annotated satellite map of NW India and Pakistan showing the location of the modern rivers, together with the drill sites mentioned in the text, as well as the paleo-channels proposed by Saini et al. (2009), Sinha et al. (2013) and Clift et al. (2012).



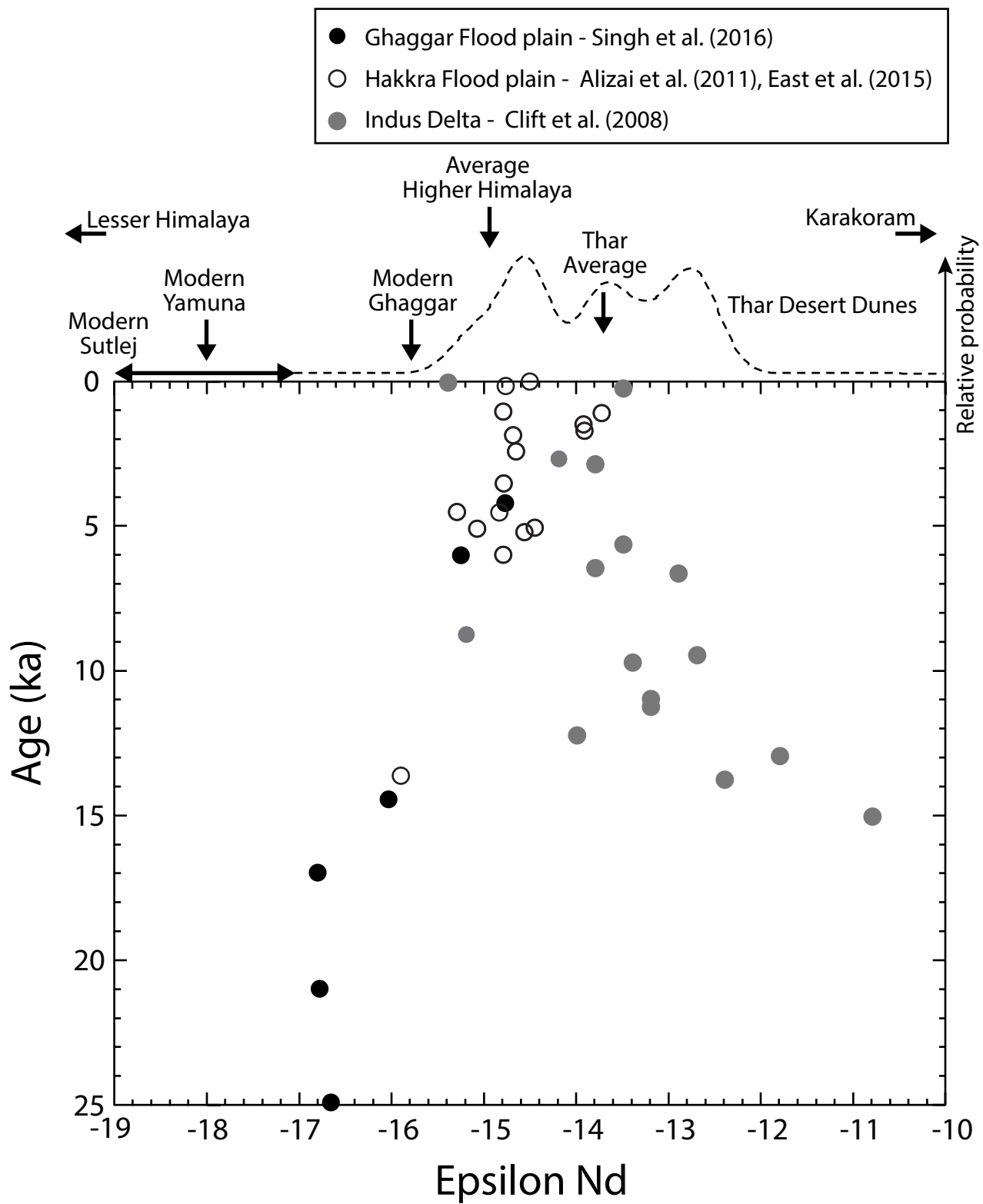


Figure 1  
Clift et al.

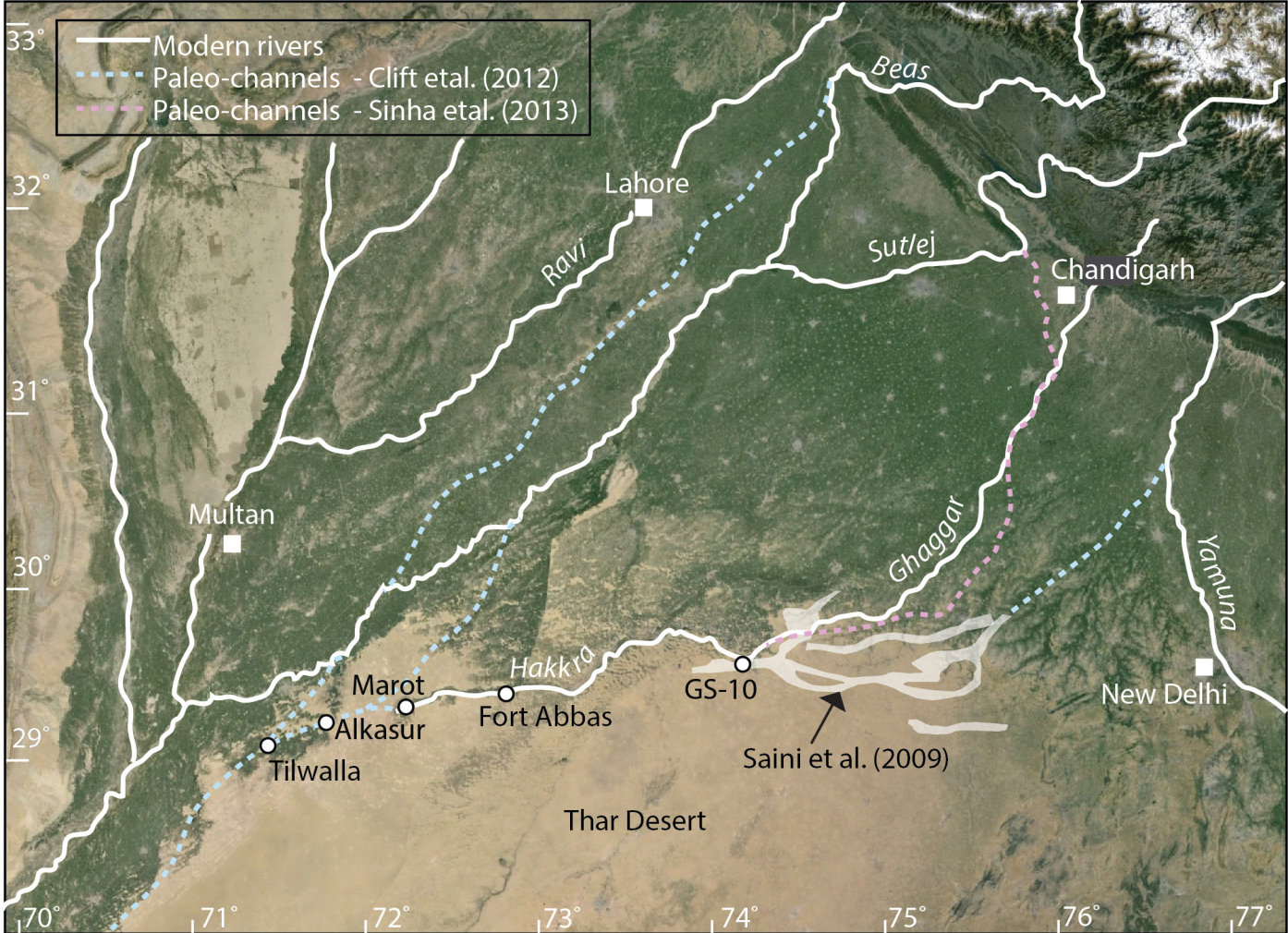


Figure 2  
Clift et al.